NEW DEVELOPMENT IN SPACE MANUFACTURING

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ABSTRACT

The progress in space manufacturing development is reviewed. The possibilities of processes in zero and low "g" environment have been considered in industry, at universities and research institutes, and government agencies. Areas of interest stimulated conceptual studies and evaluation of economical aspects. In-depth assessment of feasibility is underway.

The tabulation of unique space processes is brought up-to-date. New processes which have emerged are discussed. The present coverage by research and technology development toward space experiments is assessed, and recommendations for future development areas are given.

We have learned recently how to leave the mechanically closed system of the earth. Rocketry has opened an escape hatch from our highest order terrestrial environment. We can describe it as the earth being completely enclosed in an Ocean of Gravity. The freedom from the ever-present gravity here impacts our thinking. It sounds at first like a trivial, easy to handle change. But be on guard; it is a change completely abstract to our experience.

It impacts the microscopic and the macroscopic technology. It even amplifies our terrestrial idea of full scale things--because the disappearance of the dead weight will allow us to build things of truly extraterrestrial dimensions.

A million years ago, our "Darwin relatives" left the Ocean of Water. We learned to escape the Ocean of Air only 300 years ago. The air-free environment--the technical utilization of the vacuum--is the basis of today's technology. Without processes in pressures below one atmosphere and all the way down to the zero atmosphere level, we would not have changed and mastered the "dark age". No steam or combustion engine, no vacuum tube and electron beam, no liquefication of gases, nor the 20th Century technology would yet be developed. The significant step, 300 years ago, was this discovery of the vacuum and its subsequent utilization for laboratory and manufacturing processes. And how easy it is to talk about all the drastic developments it brought about, like playing the Monday morning quarterback.

Let's wake up now to the fact that we are witnessing another historical event--the discovery of permanent weightlessness. We must learn and become accustomed to the many novel things about the processes in environment below one "g", all the way down to the zero "g" level. The advent of zero "g" technology is the significant step into a new age of technology and we are the original participants; let's learn how to master this challenge of the Century.

How can we learn it? What does learning mean? Learning means doing something wrong. Otherwise doing it right immediately means you knew it already; you did not have to learn it in the first place. Let's wake up and go to work.

The major importance of the weightless environment lies in the fact that liquid materials become objects in their own right. From our terrestrial experience, liquids alone practically do not exist. They always need a container, and buoyancy and thermal convection during the interaction with other liquids, solids and gases are overshadowing, preventing many processes. Furthermore, on macroscopic scale, the molecular forces such as cohesion and adhesion are a set of rather disturbing influences versus the large gravity forces and rarely considered to be process determining factors. Weightless environment removes all these barriers from liquids.

In Figure 1, unique space processes which are presently under investigation are tabulated. Under A, processes are listed which use the buoyancy and thermal convection free environment and under B, the processes which are controlled by the inherent cohesion and adhesion forces. Also shown are the materials groups presently involved and the potential product groups which might emerge during follow-on space manufacturing activities.

S&E-ME-DIR 109	SPACE MANUFACTURING UNIQUE TO WEIGHTLESS ENVIRONMENT	SUMMARY

SPACE PROCESSES UNDER INVESTIGATION		MATERIAL GROUPS	PRODUCT GROUPS
A. BUOYANCY AND THERMAL CONVECTION FREE PROCESSES: TOTAL 28			
1. FREE AND CAPTIVE SUSPENSION	2		
2. MIXING	1		
3. SEPARATION & PURIFICATION	5	METALS	BALLS, SOLID AND HOLLOW, PRECISION PARTS
4. ALLOYING & SUPERSATURATION	2	CERAMICS	HIGH STRENGTH-TEMPERATURE COMPONENTS,
5. COMPOSITE CASTING	3	GLASSES	FILAMENTS, MEMBRANES, COMPOSITE
6. SOLIDIFICATION	6	BORON	STRUCTURES, COATINGS
7. DEPOSITION	2	ORGANICS	OPTICAL BLANKS AND COMPONENTS, ABRASIVES,
8. NUCLEAR	1	COMPOUNDS	ISOTOPES, NUCLEAR FUELS
9. CHEMICAL	3	CULTURES	ELECTRONIC COMPONENTS AND CRYSTALS,
10. BIOLOGICAL	3		SUPERCONDUCTORS
			VACCINES
B. COHESION AND ADHESION CONTROLLED PROCESSES: TOTAL 14			
1. SURFACE TENSION CASTING	6		
2. SURFACE TENSION DRAWING	3		
3. ADHESION CASTING	1		
4. BLOW CASTING	1		
5. CONTROLLED DENSITY CASTING	3		
TOTAL A AND B: 42			

FIGURE 1

A1 is the most typical of all weightless process: the Free and Captive Suspension of Materials. On earth, we help ourselves with levitation melting, which is limited to very small amounts of certain metals and high temperature ranges. How large and involved the possibilities of operation in zero "g" environments really are is shown in Figure 2. Here is a detailed definition of Free Suspension. There are presently two specific studies underway. More investigations are planned.

Process A2 concerns just the operation of mixing or blending in weightless environment, and there is one investigation specifically in this direction.

Process A3, Separation and Purification, is a newcomer since last year's meeting. Five investigations have developed in this area, and Figure 3 shows the involvement. Here is the present state of definition for zero "g" separation.

Processes A4 and A5, Alloying and Supersaturation and Composite Casting, are well covered throughout these presentations.

Process A6, Solidification in Weightless Environment, is one of the most attractive areas where basic improvements or even achievement of new type materials look promising. There are new operations seen in amorphous solidification, controlled crystallization, single crystal solidification, directional solidification and supercooled solidification or coining.

Process A7, Deposition in Weightlessness, carries the promise of dislocation free plating and even improved diamond deposition.

Process A8, the Making of Isotopes and Nuclear Fuels, will be discussed later in another presentation.

Process A9, the Chemical Processes in Zero Gravity, is a new area under recent consideration, and you will hear about these potential processes in other presentations. The last chart in this presentation will help to make you aware of the extreme vacuum which can be achieved even in the relatively low orbit of our future Space Station.

Process A10, the Biological Process area, is new as well, and there have already been three special presentations about it.

S&E-ME-DIR 109	FREE AND CAPTIVE SUSPENSION PROCESSES IN WEIGHTLESS ENVIRONMENT	PROCESS A1 DEFINITION

ENVIRONMENTAL CONDITIONS

a. FREE SUSPENSION IN INDIVIDUAL ORBIT

b. CAPTIVE SUSPENSION
- STING POSITIONING
- DIFFERENTIAL GAS PRESSURE POSITIONING
- ELECTROMAGNETIC FIELD POSITIONING

MATERIAL CONDITIONS

STATE OF MATTER:
- SOLID POWDERS, FIBERS, PARTS
- LIQUID
- GASEOUS

PROCESS CONDITIONS

SUSPENSION IN ONE PIECE, LIQUID OR SOLID

IMMISCIBLE LIQUID MATERIALS
LIQUID AND SOLID MATERIALS
LIQUID AND GASEOUS MATERIALS

SOLID MATERIALS PARTICLES MIXED IN VACUUM
SOLID MATERIALS PARTICLES MIXED IN GAS
SOLID + LIQUID + GASEOUS MATERIALS MIXED

FIGURE 2

S&E-ME-DIR 109	SEPARATION AND PURIFICATION IN WEIGHTLESS ENVIRONMENT	PROCESS A4 DEFINITION

CENTRIFUGAL SEPARATION
(FREE OR IN CONTAINER)

VELOCITY SEPARATION
(CONTINUOUS CONDENSATION; SELECTIVE MEMBRANES)

ELECTROSTATIC SEPARATION
(ELETROPHORESIS)

MAGNETIC SEPARATION
(MASS SPECTROMETER)

HIGH VACUUM REFINEMENT
(FREE CENTRIFUGATION)

FIGURE 3

The processes under B use the molecular forces as process controlling factors. Here the list actually has not changed since last year, but the utilization of the surface tension or free casting of precision bodies and high temperature materials has found large interest as evident from the six experiments under investigation, which have already been presented. The casting means putting under consideration the total process to the solidified component, while the free suspension, the mixing, separation and purification are either the subject of an experiment in itself or are playing only then a supporting role within the total casting process.

Surface tension drawing has found application in filament making and proposals for directional solidification. The actual drawing of membranes from inorganic materials is still an area of the future.

Adhesion casting has as well not yet found application beyond preliminary study of the process. This is true for the blow casting, which essentially will produce the hollow precision shapes, and the controlled density casting.

The material groups presently involved are metals, ceramics, glasses, boron, and organic compounds and cultures. The product groups which can be visualized in future space manufacturing activities are as follows:

Balls, solid and hollow, precision parts
High strength-temperature components, filaments, membranes, composite structures, coatings
Optical blanks and components, abrasives, isotopes, nuclear fuels
Electronic components and crystals, superconductors
Vaccines

Figure 4 demonstrates that extreme high vacuum of high pumping capacity can be made available in the wake of a rarefied flow shield. Air-free chemical preparation proposals might be greatly enhanced by this new approach.

The presentations which follow will interpret the presently known processes and cover science and technology aspects. We will also look at some more advanced processing prospects and have a grandiose look into the far future, for instance by visualizing a space factory for providing the earth with nuclear fuel. This is the end of the introductory presentation. In the beginning, you were reminded that today's technology started just 300 years ago with the discovery of zero pressure--the vacuum. So we have since then brought energy under control and established a closed cycle in food production. This is what distinguishes us from the apes, that we do not only harvest--we

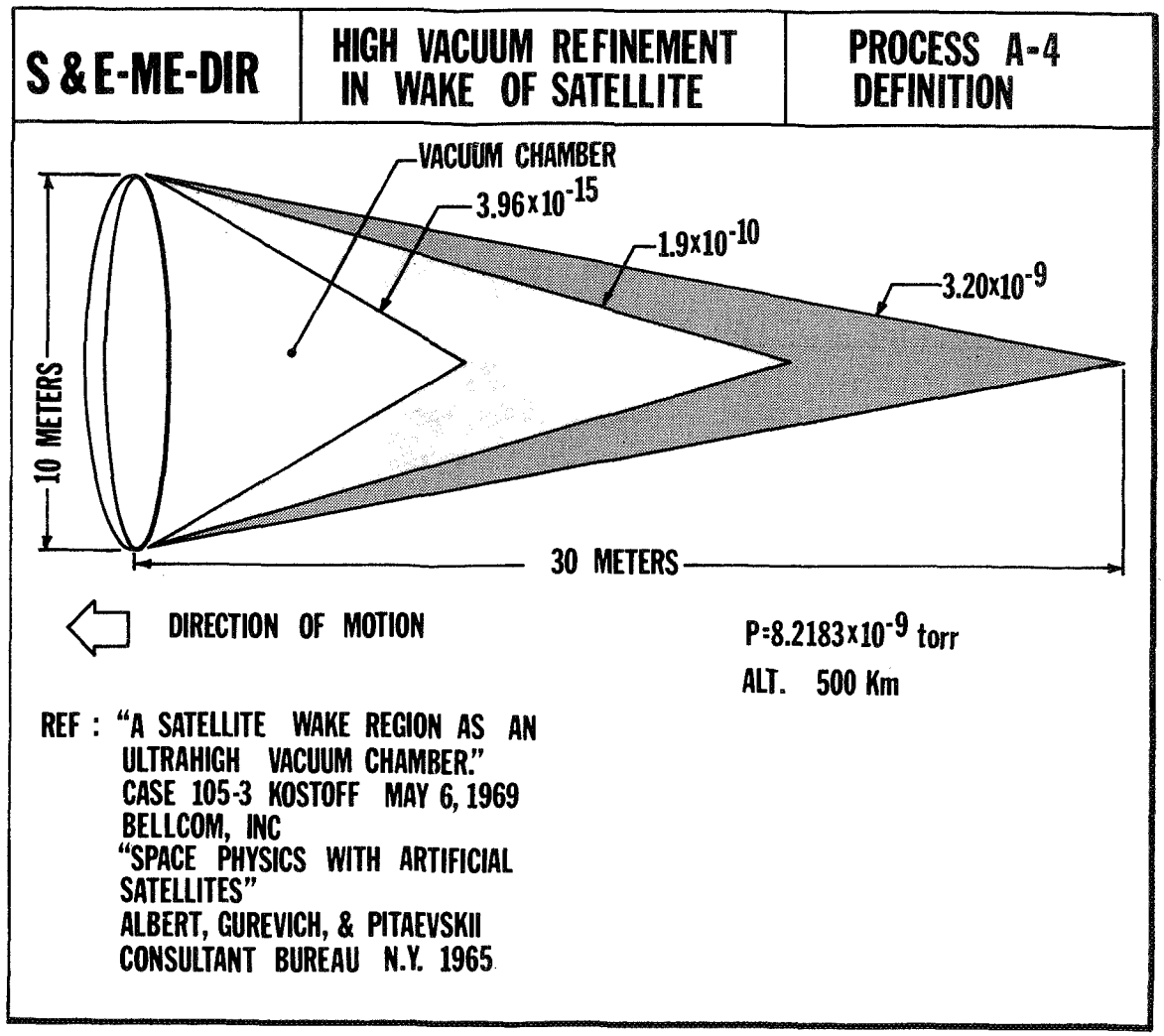
S & E-ME-DIR
HIGH VACUUM REFINEMENT IN WAKE OF SATELLITE
PROCESS A-4 DEFINITION
VACUUM CHAMBER
3.96x10-15
1.9x10-10
3.20x10-9
10 METERS
30 METERS
DIRECTION OF MOTION
P=8.2183x10-9 torr
ALT. 500 Km
REF : "A SATELLITE WAKE REGION AS AN ULTRAHIGH VACUUM CHAMBER."
CASE 105-3 KOSTOFF MAY 6, 1969
BELLCOM, INC
"SPACE PHYSICS WITH ARTIFICIAL SATELLITES"
ALBERT, GUREVICH, & PITAEVSKII
CONSULTANT BUREAU N.Y. 1965

FIGURE 4

produce what we need as well. There is only one gap left open, that is in the open loop fuel economy. We cannot reproduce the fuels we take from the earth. Maybe we are now on the way toward learning how to someday replenish our fuel needs from space.

You should test your daily processes to discover the very often hidden and indirect role which gravity plays. Review attractive concepts of the past which failed, and toy with what zero "g" can change. New developments start with the discovery of new concepts--that is the "non-mathematical" portion of science and engineering. Newton had to postulate first the concept of general gravitational attraction just from watching the apple fall. Einstein had to postulate the concept of matter-energy equivalence first. Mathematics comes later and works only if we are lucky enough to have a concept that is right, and most of the simple concepts are right. Zero "g" has the beautiful effect of simplification of involved terrestrial processes. Just think about it.

Don't hesitate--the timing now is right. Let's go to work on the exploitation of space--an area of great promise and even greater challenge.